

1 **CLAIMS**

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3 1. A method providing topology control to a distributed wireless  
4 multi-hop network comprising a plurality of nodes, the method comprising:

5 for each node, discovering a set of neighboring nodes of the nodes using a  
6 set of incoming signals from the neighboring nodes, the incoming signals being  
7 responsive to receipt by the neighboring nodes of an outgoing signal from a  
8 respective node of the nodes;

9 for each node, making a respective decision about a substantially optimal  
10 transmission power to communicate with at least one subset of the neighboring  
11 nodes, the respective decision being based on the incoming signals and being  
12 independent of positional information;

13 for each node, maintaining communications with the at least one subset to  
14 provide connectivity between each of the nodes.  
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16 2. A method as recited in claim 1, wherein collectively each respective  
17 decision provides substantially complete connectivity between the nodes in a  
18 power efficient manner.  
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20 3. A method as recited in claim 1, wherein an incoming signal  
21 comprises directional information.  
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1           4. A method as recited in claim 1, wherein an incoming signal  
2 comprises directional information and an indication of transmission power used by  
3 a neighboring node of the neighboring nodes to communicate the incoming signal.

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5           5. A method as recited in claim 1, further comprising:  
6 identifying a particular cone of degree  $\alpha$  that is within a boundary node's  
7 transmission radius that is not covered by at least one other node of the nodes,  $\alpha$   
8 being less than or equal to  $5\pi/6$ ; and

9 decreasing the boundary node's transmission radius to exclude other nodes  
10 of the nodes that were acquired within the boundary node's transmission radius as  
11 part of an attempt to communicate with a nodes of the nodes in the particular cone.

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13           6. A method as recited in claim 1, further comprising:  
14 detecting a change in topology of the wireless multi-hop network by a first  
15 node of the nodes, the change corresponding to a second node of the nodes  
16 entering or leaving a radius of coverage corresponding to the first node; and

17 responsive to detecting the change, dynamically reconfiguring the at least  
18 one subset of nodes with which the first node maintains communications to  
19 provide collective connectivity between each of the nodes in a manner that reflects  
20 the change.

1           7. A method as recited in claim 1, further comprising removing a special  
2 edge from the wireless multi-hop network, an edge being a communication  
3 pathway between two nodes of the nodes, and wherein an edge is a special edge if:  
4 (a) a first node of the at least two nodes is inside of a first transmission radius that  
5 corresponds to a second node of the at least two nodes; and (b) the second node is  
6 outside of a second transmission radius that corresponds to the first node.

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8           8. A method as recited in claim 1, wherein discovering the neighboring  
9 nodes further comprises:

10           broadcasting the outgoing signal in all directions at a portion of a  
11 substantially optimal termination power;

12           receiving the incoming signals; and

13           wherein making the respective decision further comprises:

14                 determining whether a predetermined criteria has been met; and

15                 responsive to determining that the predetermined criteria has not  
16 been met:

17                         (a) increasing the portion by a quantum;

18                         (b) re-broadcasting the outgoing signal at the portion;

19                         (c) receiving a set of incoming signals;

20                         (d) determining whether the predetermined criteria has been  
21 met; and

22                         (e) responsive to determining that the predetermined criteria  
23 has not been met, repeating (a) through (e) until either the predetermined criteria is  
24 met or until the portion reaches the substantially optimal termination power.

1           9.    A method as recited in claim 8, wherein the substantially optimal  
2 termination power is less than or equal to a node's maximum transmission power.

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4           10.   A method as recited in claim 8, wherein the predetermined criteria is  
5 based on identifying at least one node of the neighboring nodes within each of a  
6 plurality of cones of degree  $\alpha$ , each cone being centered on the respective node  
7 and spanning a degree of  $\alpha/2$  on each side of the at least one node, the cones  
8 collectively spanning  $2\pi$  degrees around the respective node.

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10          11.   A method as recited in claim 10, wherein  $\alpha \leq 5\pi/6$ .

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12          12.   A method as recited in claim 1, wherein an edge is a communication  
13 pathway between at least two nodes of the nodes, wherein connectivity in the  
14 multi-hop network is represented by a plurality of edges in a topological graph,  
15 and wherein the method further comprises removing a redundant edge from the  
16 wireless multi-hop network.

1           13.    A method as recited in claim 12, wherein removing the redundant  
2 edge further comprises:

3           assigning each edge (u, v) an edge ID as represented by:

4           
$$\text{eid}(u, v) = (i_1, i_2, i_3),$$

5           where  $i_1 = d(u, v)$ ,  $i_2 = \max(\text{node IDs of } u \text{ and } v)$ , and  $i_3 = \min(\text{node IDs of}$   
6  $u \text{ and } v)$ ; and

7           comparing edge IDs based on lexicographical order, wherein given any  
8  $\theta \leq \pi/3$  and given any pair of edges (u, v) and edges (u, w) such that angle  
9  $\angle vuw < \theta$ , a communication pathway between nodes (u, v) is a redundant edge if a  
10 first edge ID of (u, v) is greater than a second edge ID (u, w).

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12           14.    A computer-readable medium comprising computer-executable  
13 instructions providing topology control to a distributed wireless multi-hop network  
14 comprising a plurality of nodes, the computer-executable instructions comprising  
15 instructions for:

16           for each node, discovering a set of neighboring nodes of the nodes using a  
17 set of incoming signals from the neighboring nodes, the incoming signals being  
18 responsive to receipt by the neighboring nodes of an outgoing signal from a  
19 respective node of the nodes;

20           for each node, making a respective decision about a substantially optimal  
21 transmission power to communicate with at least one subset of the neighboring  
22 nodes, the respective decision being based on the incoming signals and being  
23 independent of positional information;

24           for each node, maintaining communications with the at least one subset to  
25 provide connectivity between each of the nodes.

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2       **15.**   A computer-readable medium as recited in claim 14, wherein  
3 collectively each respective decision provides substantially complete connectivity  
4 between the nodes in a power efficient manner.

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6       **16.**   A computer-readable medium as recited in claim 14, wherein an  
7 incoming signal comprises directional information.

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9       **17.**   A computer-readable medium as recited in claim 14, wherein an  
10 incoming signal comprises directional information and an indication of  
11 transmission power used by a neighboring node of the neighboring nodes to  
12 communicate the incoming signal.

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14       **18.**   A computer-readable medium as recited in claim 14, wherein the  
15 computer-executable instructions further comprise instructions for:

16       detecting a change in topology of the wireless multi-hop network by a first  
17 node of the nodes, the change corresponding to a second node of the nodes  
18 entering or leaving a radius of coverage corresponding to the first node; and

19       responsive to detecting the change, dynamically reconfiguring the at least  
20 one subset of nodes with which the first node maintains communications to  
21 provide collective connectivity between each of the nodes in a manner that reflects  
22 the change.

1           **19.**   A computer-readable medium as recited in claim 14, wherein the  
2 computer-executable instructions further comprise instructions for:

3           identifying a particular cone of degree  $\alpha$  that is within a boundary node's  
4 transmission radius that is not covered by at least one other node of the nodes,  $\alpha$   
5 being less than or equal to  $5\pi/6$ ; and

6           decreasing the boundary node's transmission radius to exclude other nodes  
7 of the nodes that were acquired within the boundary node's transmission radius as  
8 part of an attempt to communicate with a nodes of the nodes in the particular cone.

9  
10           **20.**   A computer-readable medium as recited in claim 14, further  
11 comprising instructions for removing a special edge from the wireless multi-hop  
12 network, an edge being a communication pathway between at least two nodes of  
13 the nodes, and wherein an edge is a special edge if: (a) a first node of the at least  
14 two nodes is inside of a first transmission radius that corresponds to a second node  
15 of the at least two nodes; and (b) the second node is outside of a second  
16 transmission radius that corresponds to the first node.

1           **21.**   A computer-readable medium as recited in claim 14, wherein the  
2 instructions for discovering the neighboring nodes further comprise instructions  
3 for:

4           broadcasting the outgoing signal in all directions at a portion of a  
5 substantially optimal termination power;

6           receiving the incoming signals; and

7           wherein making the respective decision further comprises:

8                   determining whether a predetermined criteria has been met; and

9                   responsive to determining that the predetermined criteria has not  
10 been met:

11                           (a) increasing the portion by a quantum;

12                           (b) re-broadcasting the outgoing signal at the portion;

13                           (c) receiving a set of incoming signals;

14                           (d) determining whether the predetermined criteria has been  
15 met; and

16                           (e) responsive to determining that the predetermined criteria  
17 has not been met, repeating (a) through (e) until either the predetermined criteria is  
18 met or until the portion reaches the substantially optimal termination power.

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20           **22.**   A computer-readable medium as recited in claim 21, wherein the  
21 substantially optimal termination power is less than or equal to a node's maximum  
22 transmission power.  
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1           **23.**    A method as recited in claim 21, wherein the predetermined criteria  
2 is based on identifying at least one node of the neighboring nodes within each of a  
3 plurality of cones of degree  $\alpha$ , each cone being centered on the respective node  
4 and spanning a degree of  $\alpha/2$  on each side of the at least one node, the cones  
5 collectively spanning  $2\pi$  degrees around the respective node.

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7           **24.**    A computer-readable medium as recited in claim 23, wherein  
8  $\alpha \leq 5\pi/6$ .

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10          **25.**    A computer-readable medium as recited in claim 14, wherein an  
11 edge is a communication pathway between at least two nodes of the nodes,  
12 wherein connectivity in the multi-hop network is represented by a plurality of  
13 edges in a topological graph, and wherein the computer-executable instructions  
14 further comprise instructions for removing a redundant edge from the wireless  
15 multi-hop network.  
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1        26.    A computer-readable medium as recited in claim 25, wherein the  
2 computer-executable instructions for removing the redundant edge further  
3 comprises instructions for:

4        assigning each edge (u, v) an edge ID as represented by:

5                 $\text{eid}(u, v) = (i_1, i_2, i_3),$

6                where  $i_1 = d(u, v)$ ,  $i_2 = \max(\text{node IDs of } u \text{ and } v)$ , and  $i_3 = \min(\text{node IDs of}$   
7  $u \text{ and } v)$ ; and

8                comparing edge IDs based on lexicographical order, wherein given any  
9  $\theta \leq \pi/3$  and given any pair of edges (u, v) and edges (u, w) such that angle  
10  $\angle uvw < \theta$ , a communication pathway between nodes (u, v) is a redundant edge if a  
11 first edge ID of (u, v) is greater than a second edge ID (u, w).

27. A computing device comprising:

a memory comprising computer-executable instructions for providing location-based topology control to a wireless multi-hop network comprising a plurality of nodes;

a processor that is operatively coupled to the memory, the processor being configured to fetch and execute the computer-executable instructions from the memory, the computer-executable instructions comprising instructions for:

for each node, discovering a set of neighboring nodes of the nodes using a set of incoming signals from the neighboring nodes, the incoming signals being responsive to receipt by the neighboring nodes of an outgoing signal from a respective node of the nodes;

for each node, making a respective decision about a substantially optimal transmission power to communicate with at least one subset of the neighboring nodes, the respective decision being based on the incoming signals and being independent of positional information;

for each node, maintaining communications with the at least one subset to provide connectivity between each of the nodes.

28. A computing device as recited in claim 27, wherein collectively each respective decision provides substantially complete connectivity between the nodes in a power efficient manner.

29. A computing device as recited in claim 27, wherein an incoming signal comprises directional information.

1           30.    A computing device as recited in claim 27, wherein an incoming  
2 signal comprises directional information and an indication of transmission power  
3 used by a neighboring node of the neighboring nodes to communicate the  
4 incoming signal.

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6           31.    A computing device as recited in claim 27, wherein the computer-  
7 executable instructions further comprise instructions for:

8               detecting a change in topology of the wireless multi-hop network by a first  
9 node of the nodes, the change corresponding to a second node of the nodes  
10 entering or leaving a radius of coverage corresponding to the first node; and

11              responsive to detecting the change, dynamically reconfiguring the at least  
12 one subset of nodes with which the first node maintains communications to  
13 provide collective connectivity between each of the nodes in a manner that reflects  
14 the change.

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16           32.    A computing device as recited in claim 27, wherein the computer-  
17 executable instructions further comprise instructions for:

18              identifying a particular cone of degree  $\alpha$  that is within a boundary node's  
19 transmission radius that is not covered by at least one other node of the nodes,  $\alpha$   
20 being less than or equal to  $5\pi/6$ ; and

21              decreasing the boundary node's transmission radius to exclude other nodes  
22 of the nodes that were acquired within the boundary node's transmission radius as  
23 part of an attempt to communicate with a nodes of the nodes in the particular cone.

1           33. A computing device as recited in claim 27, further comprising  
2 instructions for removing a special edge from the wireless multi-hop network, an  
3 edge being a communication pathway between at least two nodes of the nodes, and  
4 wherein an edge is a special edge if: (a) a first node of the at least two nodes is  
5 inside of a first transmission radius that corresponds to a second node of the at  
6 least two nodes; and (b) the second node is outside of a second transmission radius  
7 that corresponds to the first node.  
8

9           34. A computing device as recited in claim 27, wherein the instructions  
10 for discovering the neighboring nodes further comprise instructions for:

11           broadcasting the outgoing signal in all directions at a portion of a  
12 substantially optimal termination power;

13           receiving the incoming signals; and

14           wherein making the respective decision further comprises:

15                   determining whether a predetermined criteria has been met; and

16                   responsive to determining that the predetermined criteria has not  
17 been met:

18                           (a) increasing the portion by a quantum;

19                           (b) re-broadcasting the outgoing signal at the portion;

20                           (c) receiving a set of incoming signals;

21                           (d) determining whether the predetermined criteria has been  
22 met; and

23                           (e) responsive to determining that the predetermined criteria  
24 has not been met, repeating (a) through (e) until either the predetermined criteria is  
25 met or until the portion reaches the substantially optimal termination power.

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2       **35.**    A computing device as recited in claim 34, wherein the substantially  
3 optimal termination power is less than or equal to a node's maximum transmission  
4 power.  
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6       **36.**    A computing device as recited in claim 35, wherein the  
7 predetermined criteria is based on identifying at least one node of the neighboring  
8 nodes within each of a plurality of cones of degree  $\alpha$ , each cone being centered on  
9 the respective node and spanning a degree of  $\alpha/2$  on each side of the at least one  
10 node, the cones collectively spanning  $2\pi$  degrees around the respective node.  
11

12       **37.**    A computing device as recited in claim 36, wherein  $\alpha \leq 5\pi/6$ .  
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14       **38.**    A computing device as recited in claim 27, wherein an edge is a  
15 communication pathway between at least two nodes of the nodes, wherein  
16 connectivity in the multi-hop network is represented by a plurality of edges in a  
17 topological graph, and wherein the computer-executable instructions further  
18 comprise instructions for removing a redundant edge from the wireless multi-hop  
19 network.  
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1        39.    A computing device as recited in claim 38, wherein the computer-  
2 executable instructions for removing the redundant edge further comprise  
3 instructions for:

4            assigning each edge (u, v) an edge ID as represented by:

5            
$$\text{eid}(u, v) = (i_1, i_2, i_3),$$

6            where  $i_1 = d(u, v)$ ,  $i_2 = \max(\text{node IDs of } u \text{ and } v)$ , and  $i_3 = \min(\text{node IDs of}$   
7  $u \text{ and } v)$ ; and

8            comparing edge IDs based on lexicographical order, wherein given any  
9  $\theta \leq \pi/3$  and given any pair of edges (u, v) and edges (u, w) such that angle  
10  $\angle vuw < \theta$ , a communication pathway between nodes (u, v) is a redundant edge if a  
11 first edge ID of (u, v) is greater than a second edge ID (u, w).